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THE

JOURNAL OF GEOLOGY

NOVEMBER-DECEMBER, 1893.

THE SUPPOSED GLACIATION OF BRAZIL.[1]

THE inquiries I have received from time to time regarding the supposed glaciation of Brazil in Pleistocene times, the doubts sometimes expressed regarding it, and the occasional appeals made to it,[2] induce me to state briefly what I know about the matter.

Strangely enough the errors of Agassiz, Hartt and Belt regarding glaciation in Brazil have been turned to account both by those who have theories that need the support they think the glaciation of Brazil would give them, and also by those who seek by means of these errors to throw discredit on the subject of glacial geology.

I believe the case has been generally dropped by geologists as not proven, but I am confident that no one wishes to ignore the evidence "merely because it runs counter to all his preconceived opinions."[3]

EARLY VIEWS OF AGASSIZ AND HARTT.

When Professor Louis Agassiz made his trip to Brazil in 1865, on board the steamer going out he gave a series of lectures in which he suggested to his assistants the possibility of the South American continent having been glaciated, and reminded them that this was one of the important subjects for their investigation.[1]

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[1] Advance quotations are made from this article by Dr. Alfred R. Wallace in Nature, Vol. 48, No. 1251, Oct. 19, 1893, 589–590.

[2] The Glacial Nightmare and the Flood, by Sir HENRY H. HOWORTH, London, 1893. MARSDEN MANSON, in the Trans. of the Geol. Soc. of Australasia, I., pt. VI., 155–170, and in the Trans. of the Tech. Soc. of the Pacific Coast, VIII., No. 2, 19. Geological and Solar Climates; their Causes and Variations, by MARSDEN MANSON, University of California, May, 1893. Ragnarok, by IGNATIUS DONELLY.

[3] WALLACE: Nature, Vol. II., 1880, 511.

I subsequently learned from Professor Hartt, who was one of the assistants, that these lectures prepared them to be convinced that glaciation had taken place in Brazil, though he himself was rather inclined to believe otherwise.

Mrs. Agassiz's book shows throughout how Professor Agassiz found on every hand, from the time he landed in Brazil till he left there, what he regarded as evidences of glacial action. In the mountains about Rio de Janeiro he found erratic boulders (pp. 86 *et seq.*); at Ereré, in the Amazon valley, he found "the only genuine erratic boulders I have seen in the whole length of the Amazon valley," (p. 418); he declared that "il n'y a pas trace des terrains tertiaires"[2] in that region, while the horizontal sediments of that valley he explained as silts thrown down in cold glacial waters behind a vast terminal moraine that stretched across the mouth of the valley (p. 426), and of which the island of Marajo was supposed to be a remnant; the table-topped hills he explained as the remnants of sediments left when this great dam broke, and the waters swept the greater part of the beds out to sea.

The lateral moraine on the south side of this great glacier he expected to find in the interior of Ceará (p. 447-8); he went to Ceará, and found at Pacatúba, near the coast, what he regarded as glacial phenomena "as legible as any of the valleys of Maine, or in those of the valleys of Cumberland in England" (pp. 456, 463).

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[1] A Journey to Brazil, by Professor and Mrs. LOUIS AGASSIZ, Boston, 1868, 15. In Mrs. AGASSIZ'S Life and Correspondence of Louis Agassiz, Boston, 1886, II., 633, it is further stated that Agassiz was confirmed "in his preconceived belief that the glacial period could not have been less than cosmic in its influence."

[2] Bul. de la Soc. Géologique de France, XXIV., 110. In a letter to Élie de Beaumont, he speaks of these beds as loess, but he gives no specific explanation of their formation. Comptes Rendus de l'Acad. des Sciences, 1867, 1269. Professor Agassiz first published his paper on the Physical History of the Amazon valley in the Atlantic Monthly for July and August, 1866; it was also published subsequently in his Geological Sketches, sec. ser. Boston, 1886. II., 153 *et seq.*, and in the Journey to Brazil.

Naturally enough these views were received in the scientific world with incredulity. As Mr. Wallace remarks, "Prof. Agassiz was thought to be glacier-mad,"[1] but his earlier observations on glaciers had been received with quite as much doubt,[2] so that the doubts have nothing to do with the case one way or the other.

Professor Chas. Fred. Hartt states in his book[3] that he was at first very skeptical about Brazilian glaciation, but that he was finally obliged to yield to the evidence collected by himself, and to confess that Agassiz was right.

It should perhaps be mentioned here, that there is a general impression that when Hartt wrote his book on the geology of Brazil, he had spent several years, and traveled widely in that country, and that the conclusions given by him are the results of all his Brazilian work. This is far from being the case. When he wrote the Geology and Physical Geography of Brazil, he had spent only a year and a half in that country; on his first trip he arrived at Rio de Janeiro, April 23, 1865, and left it on July of the following year;[4] on his second trip, he reached Pará, July 11, 1867,[5] and returned from Rio in September of that year,[6] making in all not more than eighteen months spent in that country up to the time his book went to press. The belief in the glaciation of Brazil, as there expressed, is therefore based upon his earliest and least trustworthy work in that region. Hartt fully recognized this afterwards, and I have often heard him say, "I wish I had known as much about geology when I wrote that book as I know now."

He subsequently made several trips to Brazil; in one to the

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[1] Nature, II., 511. LYELL's Principles of Geology, New York, 1889, 1, 466.

[2] Bul. de la Soc. Géol. de France, 1867-8, XXV., 685.

[3] Geology and Physical Geography of Brazil, Boston, 1873, 29.

[4] Agassiz, Journey, 46 and 540.

[5] American Naturalist, I., 648.

[6] Geology and Physical Geography, 201.

Amazon valley he examined the table-topped hills[1] which Agassiz had referred to glacial action, and the boulders he had called "the only genuine erratic boulders" he had seen in the Amazon valley. Already, in 1867, Professor James Orton, who scouts the idea of the glaciation of the Amazonas, had discovered at Pebas, in the supposed glacial sediments, "marine or perhaps rather brackish water Tertiary fossils."[2]

In 1871 Hartt found the supposed erratics of the Amazon valley to be boulders of decomposition derived from trap dikes near at hand, and stated that he "did not see, either at Ereré or in any part of the Amazonas, anything that would suggest glaciation."[3] He still clung, however, to the idea that the highland of Brazil to the south had been glaciated.[4]

Unfortunately Hartt has left no further record of his later views upon this subject, but that his views underwent a radical change I know as positively as one can know the opinions of another person. I went with him to Brazil in 1874, was with him in his work there until his death in 1877, and remained yet five years later—in all eight years in that country. Under his direction I did more or less work in the mountains about Rio de Janeiro for the purpose of sifting the evidence of glaciation in that region, and I am glad to say, in justice to the memory and scientific spirit of my former chief and friend, that long before his death he had entirely abandoned the theory of the glaciation of Brazil, whether general or local, and that the subject had ceased to receive further attention, even as a working hypothesis. So much for Hartt's opinions.

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[1] Bulletin of the Buffalo Soc. of Natural History, 1874, 201.

[2] On the Valley of the Amazon, by JAMES ORTON, Proc. Am. Assoc. Adv. Sci., 1869, XVIII., 195–9; On the Evidence of a Glacial Epoch at the Equator, by JAMES ORTON, The Annals and Magazine of Natural History, 1871, VIII., 297–305.

The Andes and the Amazon, by JAMES ORTON, N. Y., 1876, 282, 560. The fossils collected by Orton are described in the Amer. Jour. Conchology, IV., 197, and VI., 192. Others are described from similar places in the Quar. Jour. Geol. Soc., XXXV., 76–88, and 763 *et seq.*

[3] Amer. Jour. Sci., 1871, 295.

[4] Ann. Rep. of the Amer. Geographical Soc. of N. Y., for the year 1870-1, 252.

Thomas Belt, the author of The Naturalist in Nicaragua, says in that volume[1] that though no ice marks are visible he has seen "near Pernambuco, and in the Province of Maranham, in Brazil, a great drift deposit that I believe to be of glacial origin."

I have seen and studied the deposits to which Belt refers; my opinion is that while they bear a certain resemblance to glacial drift they are entirely devoid of positive evidence of glacial origin. The method of their formation is explained in another part of this paper.[2]

AGASSIZ'S CHANGE OF VIEWS.

It is appropriate that I here quote from Professor N. S. Shaler, a former pupil of Professor Agassiz:[3]

> "There has been a good deal of discussion concerning the former existence of glaciers in the valley of the Amazon. Agassiz, to whom we owe the first suggestion of the value of glaciation as a great geological agent, at one time thought it likely that the valley of this great river had been the seat of a glacier that poured its ice from the Andes nearly down to the sea. This, which was hardly more than a suggestion put forth for the discussion of geological students, was, I believe, practically abandoned by this illustrious naturalist before his death, (In this assertion I have embodied the results of several remarks by my late master on this subject made during the last two years of his life. It is satisfactory to know that the only considerable mistake he made in the matter of glaciation was corrected by his own reflections on the subject. N. S. S.) and has been found to be an essentially mistaken view. The late Professor Hartt, geologist of Brazil, at one time thought some of the debris in the mountain districts near Rio de Janeiro was of glacial origin, but this suggestion has never been submitted to discussion, and can have no weight against the other evidence of a negative kind that goes to show that glaciation, save in higher mountain countries, has never extended into the intertropical regions."

[1] The Naturalist in Nicaragua, by Thomas Belt, F.G.S., 2d ed. London, 1888, 265.

[2] It has been asked how I reconcile Belt's statements regarding glaciation in Nicaragua with my inability to find trustworthy evidence of glaciation at a similar south latitude. I don't try to reconcile them; I am simply dealing with the facts as I know them in Brazil. I have never seen the Nicaraguan deposits, but I can't avoid suspecting that they will turn out like the Brazilian ones, J. Crawford's moraines and "moutonnéd ridges" to the contrary notwithstanding. (Proc. Amer. Assoc. Adv. Sci., XL., 265, and Science, XXII., No. 263, p. 270).

[3] Glaciers, by N. S. SHALER and W. M. DAVIS, Boston, 1881, 47.

In 1872 Agassiz went through the Straits of Magellan in charge of the natural history work of the Hassler Expedition. On that voyage he touched at Montevideo and at many points south of that place, through the straits, and along the west coast. The letters written by him on this trip suggest very strongly, if they do not conclusively show, that he had at this time already abandoned the idea that Brazil had been glaciated. Speaking of certain boulders seen by him on the Cerro at Montevideo, Mrs. Agassiz observes[1] that "As these were the most northern erratics and glaciated surfaces reported in the southern hemisphere," etc. From this it appears that he no longer regarded the Brazilian boulders as erratics.

After Agassiz had examined the glacial phenomena of the Straits of Magellan and of the southern part of the continent, he sent a report to the Superintendent of the U. S. Coast Survey, dated at Concepcion Bay, June 1, 1872.[2] This article also bears evidence that he no longer regarded Brazil as having been glaciated. In one place he says,[3] "I am prepared to maintain that *the whole southern extremity of the American continent* has been uniformly moulded by a continuous sheet of ice." The italics are mine. In the next paragraph he says, "The first unquestionable *roches moutonnées* I saw were upon the nearest coast opposite Cape Froward." Again he says (p. 271): "The equatorial limit of this ice sheet both in the northern and the southern hemisphere is part of the problem upon which we have thus far fewest facts in our possession. In South America I have now traced the facts *from the southernmost point of the continent uninterruptedly to 37° S. latitude on the Atlantic* as well as the Pacific coast." Again

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[1] Louis Agassiz, his Life and Correspondence, Boston, 1886, II., 712. Rep. U. S. Coast and Geodetic Survey for 1872, 215. Nature, 1872, VI., 69. Evidently Burmeister does not regard the boulders cited as glacial, for he uses the expression, "phénomènes de glaciers chez nous, et dont nous n'avons nulle part la preuve." République Argentine, II., 214, also 392, 393. The same blocks are described by Darwin in his Geological Observations, 432. He does not seem to regard them as erratics.

[2] Published in the New York Tribune of June 26, 1872, and reproduced in Nature 1872, VI., 216, 229 and 260.

[3] Nature, 1872, VI., 230.

(p. 272) he speaks of having traced the palpable evidence of glaciation "from Montevideo on the Atlantic to Talcahuano on the Pacific coast." Speaking of evidence at Concepcion Bay he says also (p. 272) "Think of it! A characteristic surface indicating glacial action in latitude 37° S. at the level of the sea!"

These quotations show as plainly as anything short of a positive statement can that Agassiz in 1872 no longer considered as trustworthy what he had formerly regarded as the evidences of glaciation in Brazil. For if he still believed in a glacier under the equator itself, why should he tell us with exclamation points to think of a glacier thirty-seven degrees nearer the pole?

BASIS OF THE THEORY.

I should be glad to leave the matter with these statements of the changes of views on the part of both advocates of the glaciation of Brazil, but persons who have theories based to a greater or less extent on the glaciation of the tropics are very reluctant to believe, in the face of the many positive statements of both Agassiz and Hartt, and of the apparently trustworthy evidence adduced by them, that the first impressions of those excellent observers, both of whom were thoroughly familiar with glacial phenomena in the north, were altogether wrong. It is not possible, neither is it necessary, to take up here the individual cases spoken of by Agassiz and Hartt as evidence of glacial action. Very nearly all the materials referred by them to the drift fall under two principal heads:

First, the so-called erratic boulders, often imbedded in what was considered boulder-clay.

Second, transported, water-worn materials.

ORIGIN OF THE BOULDERS.

The boulders believed to be erratics are not erratics in the sense implied, though they are not always in place. The first and most common are boulders of decomposition, either rounded or subangular, left by the decay of granite or gneiss. Sometimes they are imbedded in residuary, and consequently unstrati-

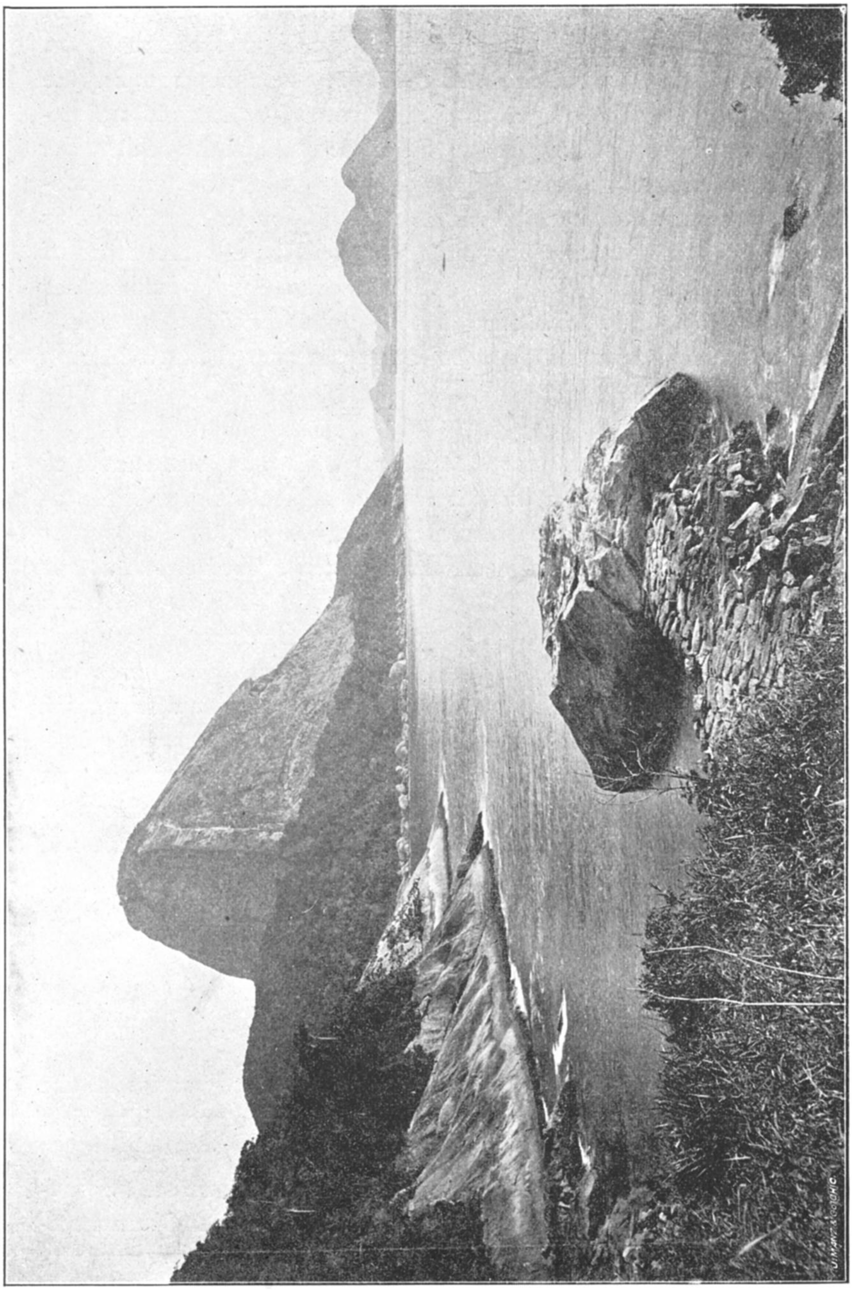

FIG. 1. Pão d'Assucur or Sugar Loaf, a Granite Peak at the Entrance of the Bay of Rio de Janeiro.

fied clays, formed by the decomposition in place of the surrounding rock. And everyone has heard of the great depth to which rocks are decomposed in Brazil.[1] The true origin of these boulders and the accompanying clays is often more or less obscured by the "creep" of the materials, or, in hilly districts, by land-slides, great or small, that throw the whole mass into a confusion closely resembling that so common in the true glacial boulder-clays. In this connection too much stress can scarely be placed upon the matter of land-slides; they are very common in the hilly portions of Brazil, and, aside from profound striations and faceting, produce phenomena that, on a small scale, resemble glacial till in a very striking manner. The fact that the boulders are of various sizes, sometimes from ten to twenty feet in diameter, and have mingled with them quartz fragments derived from the veins that traverse the crystalline rocks from which they are derived, adds to the resemblance of these materials to certain glacial products. Such boulders, however, are by no means confined to the vicinity of Rio de Janeiro, but are common throughout Brazil wherever there are granites or gneisses. They have been seen by the writer in the Amazon valley (Araguary River) in the interior of Pernambuco,[2] Parahyba do Norte, Alagôas, Sergipe, Bahia, Rio de Janeiro, Minas Geraes, São Paulo, Paraná, and Matto Grosso.

The positions in which such boulders are often found are worthy of note, though one who felt disposed to regard them as transported blocks would probably not consider their positions as inconsistent with the glacial theory of their orgin. They are abundant about the bases of granite hills and mountains where they have been formed by the exfoliation of the great blocks and slabs produced by the secular decay of the hills and mountains. There are hundreds of rude boulders at the southeast base

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[1] DARWIN: Geological Observations, 427; LIAIS: Climats, Géologie, etc., 2; PISSIS: Men. Hist. Inst. de France, X., 538; DERBY: Amer. Jour. Sci., 3d Ser., XXVII., 138; MILLS: Amer. Geologist, III., 351.

[2] In the American Naturalist, 1884, XVIII., 1189, I have given a sketch of some boulders found in the state of Pernambuco; see also p. 1187 of that vol.

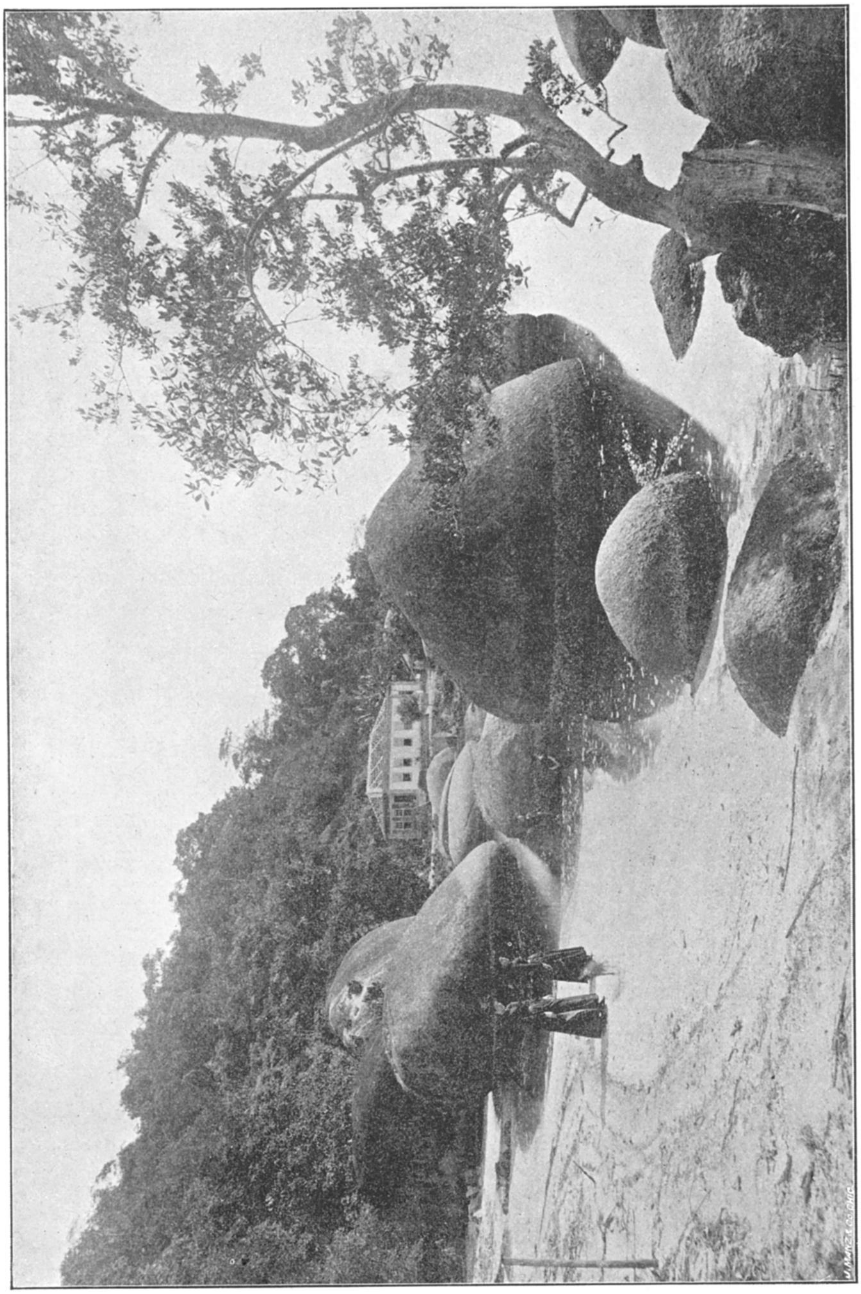

FIG. 2. Boulders of Decomposition, Island of Paquetá, in the Bay of Rio de Janeiro.

of the Sugar Loaf at the entrance to the harbor of Rio, at the east base of the Corcovado, and about every such mountain in the vicinity of Rio de Janeiro. They[1] rest on the summits and margins of the high, sharp mountain peaks; on the top of the Sugar Loaf at the entrance of the Rio harbor, for example, there are several such boulders, one of which is thirty feet in diameter; the top of the Gavea, the flat-topped mountain southwest of Rio, has hundreds of boulders on its summits. Agassiz mentions such boulders on the edge of rock basins (Journey, 493). He "was at a loss how to explain how loose masses of rock, descending from the heights above should be caught in the edges of these basins, instead of rolling to the bottom." The fact is that the blocks referred to originated, not in the heights above, but just where they now lie, as is shown beyond question by occasional quartz veins passing from the boulders into the rocks upon which they rest.[2]

In some of the shallow parts of the Bay of Rio de Janeiro what were once small islands have had the residuary soils removed and great nests of such boulders project from the water.[3] On the island of Paquetá in the bay are some beautiful examples of such boulders lying in the water's edge. I am fortunately able to give an illustration showing the Paquetá boulders which may be taken as a type of those found in and about the Bay of Rio de Janeiro.

The second method by which these boulders have been formed is quite similar to the first, but instead of being cores of granite or gneiss, they have been derived by the same process of exfoliation and decomposition from the angular blocks into which the dikes of diorite, diabase, or other dark colored rocks break up. Their color marks them as quite different from the surrounding granites, and the dikes themselves are almost invariably concealed. Moreover, these dikes not infrequently contain inclusions of still different rocks and we thus occasionally have boulders of various kinds of rocks mingled together. The residuary clays derived from the decomposition of these dikes are somewhat different in color from those yielded by the granites, so that when "creep" or land-slides add their confusion to the original relations of the rocks, the resemblance to true glacial boulder-clays is pretty strong. The chance of discovering the source of these boulders is further decreased by the depth to which the mass of the rock has decayed, and by the impenetrable jungles that cover the whole country and so effectually limit the range of one's observation. Dikes such as these last mentioned are not uncommon in the mountains of Rio de Janeiro. Indeed what have generally been regarded as the very best evidences of Brazilian glaciation,[1] some of the boulders near the English hotel in Tijuca, fall under this head, though some of them are of gneiss. The fact is that the great mountain masses about Rio are of granite or gneiss, while some of the boulders come from dikes or other dark-colored rock high on their sides, dikes which were not visited by Agassiz or Hartt.[2] There is a good example of a dike breaking up in boulders at the gap through which the road passes from the Jardim Botanico to the Gavea near the City of Rio. At this place the ground is covered to a depth of fifteen feet or more with clays through which are mingled boulders of diorite and granite and fragments of quartz. Further east, at a lower level, some of the clays have been washed over and contain subangular fragments of quartz, some of them two feet in diameter, many of which are somewhat water-worn. It is perhaps worth mentioning that these water-worn quartz fragments imbedded in clays were regarded by Hartt as the best evidence of glaciation. They were finally eliminated as such evidence near the end of a rainy season by my finding a landslide filling up a small ravine in which the bed of the stream had been strewn with similar quartz fragments, and the whole buried beneath a slide of crumpled clays. A highly instructive lesson can be had on the subject of boulders and clays, their origin and relations to the so-called drift of Brazil from Professor Derby's paper on nephelene rocks in Brazil.[1] Anyone reading that article can readily fancy how Professor Agassiz, in a flying trip across São Paulo and Minas, would have interpreted these clays and boulders of different kinds and different colors.

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[1] Sometimes boulders accumulate on one side of a hill or peak and not on the opposite side. This is well illustrated in the case of the Sugar Loaf. On the side facing the ocean there are thousands of boulders, many of them of enormous size, while on the opposite side where there is less surf there are but few. The reason for this difference is that there is a large dike-like ledge of hard rock exposed on the seaward side of the peak. This ledge does not appear on the opposite side where the mass is softer and weathers away evenly without leaving good boulder-forming fragments about the base. The ledge referred to is shown in the accompanying illustration.

[2] In SHALER and DAVIS' Glaciers, plate XXII., is given an example of boulders of decomposition in Central India. Exactly similar cases are common in the granitic and gneissic areas of Brazil.

[3] See also BURMEISTER'S Reise nach Brasilien, Berlin, 1852, 111, 112.

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[1] A Journey to Brazil, 86 *et seq.*; AGASSIZ: Geological Sketches, Boston, 1885, II., 155 *et seq.* HARTT'S Geol. and Phys. Geog. of Brazil, 24–30.

[2] Darwin mentions boulders and dikes seen at Rio de Janeiro, (Geological Observations, pt. II., ch. XIII., 425; also Trans. Geol. Soc. London, 2d Series, 1842, VI., 427, note). Professor O. A. Derby sent Rosenbusch specimens of diabase from twelve dikes in the neighborhood of Rio de Janeiro, varying from twenty centimetres to several metres in thickness. See Dr. E. O. HOVEY'S descriptions of these rocks in Tschermak's Min. u. Petrog. Mittheilungen, 1893, XIII., 211–218.

In regard to the so-called erratics I should mention also the opinion of another observer and writer upon Brazilian geology. Emmanuel Liais, formerly director of the Imperial Observatory at Rio de Janeiro, is very positive that there are no evidences whatever of glaciation in Brazil. Of the boulders supposed to be erratics, he says :[2]

> "These boulders though numerous are always in the immediate neighborhood of the veins from which they are derived. . . . . Though presenting sometimes the appearance of erratics by their abundance and rectilinear arrangement, they are not transported boulders, and have nothing in common with erratic phenomena. . . . . I have not been able to find any signs of the existence of a boulder that can be regarded as erratic and coming from a region distant from the one where it is found. In the vicinity of these isolated boulders one always finds dikes, veins or simply masses or boulders of the same material intercalated with the terrain in place."

He speaks of the occurrence of dikes of diorite from which many of the boulders cited by Agassiz have been derived. More than a score of statements of a similar nature may be cited from Liais' book.

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[1] Quar. Jour. Geol. Soc., 1887, XLIII., 457–473.

[2] Climats, Géologie, etc., du Brésil, Paris, 1872, 18.

Count de la Hure has also pointed out how diorite breaks up into boulders, and cites in evidence some of the very cuts on the Pedro II. Railway which Agassiz and Hartt refer to the drift. Saldanha da Gama in speaking of the exfoliation and decomposition of granite rocks described by Count de la Hure and Capanema says :[1]

> "This and many other facts gathered by the Brazilian naturalist in his observations on diorite and other rocks of that class led the eminent Swiss geologist to point out that the study of the drift in Brazil will not be well understood so long as one hasn't a thorough knowledge of the decomposition of the rocks."

He also refers to the fact that these phenomena may be observed in several of the Brazilian provinces.

The two kinds of boulders above mentioned are common in the regions of crystalline rocks ; a third kind is found in those parts of eastern Brazil that are covered, or were formerly covered, by Tertiary sediments, namely in the State of Bahia, and thence northward to the Amazon valley. These Tertiary deposits contain beds of sandstone that are sometimes locally changed upon exposure to the hardest kind of quartzite. Most of the associated beds are friable and easily eroded, so that when the surrounding strata have been removed there are left behind a few blocks of quartzite, varying in size from a foot to four feet in diameter. These boulders are so unlike the rocks from which they have been derived and by which they are surrounded, that unless one has given special attention to the study of Tertiary sediments in that region he is liable to be much puzzled and even misled by them.[2]

ORIGIN OF THE WATER-WORN MATERIALS.

The second class of evidences by which Agassiz and Hartt were misled consisted of transported, water-worn materials.

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[1] Revista do Instituto Historico do Brazil, 1866, XXIX., 421 *et seq.*

[2] See BRANNER's Cretaceous and Tertiary Geology of the Sergipe-Alagôas Basin of Brazil. Trans. Amer. Phil. Soc., XVI., 1889, 419–421.

These materials are made up of boulders, cobbles, and gravels, sometimes assorted and sometimes having sand and clay mixed with them, and are spread far and wide, though irregularly, over all the Tertiary and Cretaceous area bordering the ocean, and extend for a long distance into the interior, and far beyond the borders of the Tertiary deposits. They were regarded by the writers in question as analogous to the water-worn materials so common in the northern drift. Had these materials been of glacial origin it is not unreasonable to expect that striated pebbles would have been found among them occasionally, but, as a matter of fact, no such marks have ever been found, though I have made the most diligent search for them. That the striæ have been obliterated by weathering agencies is out of the question, because the preservation of the water-worn and pitted faces of the pebbles shows plainly enough that striated faces would have been preserved equally well had they ever existed. The origin of these water-worn materials has already been explained elsewhere, and from that article the following quotation is made :[1]

> "This formation is spread over the hills and valleys of the Sergipe-Alagôas basin and over the adjacent country in the form of a thin coating of cobblestones, pebbles and sand, sometimes loose and sometimes cemented into a pudding-stone as much as ten feet in thickness, and, when exposed, stained black by manganese. It caps the summit of the tertiary plateaux or their outliers, and it is frequently strewn along down the sides of hills and accumulated in the valleys. It is not confined to the geographic limits of the Cretaceous or Tertiary, but is found further inland and far beyond the present limits of these formations. It is everywhere more or less irregular in thickness, and nowhere can it be said to be universal or continuous. The writer has seen this material throughout Sergipe and Alagôas, in Parahyba, and as far inland as the head waters of the Rio Ipanema in the interior of the province of Pernambuco, where there is no remnant of stratified Tertiary beds. Between the lower Rio São Francisco and the frontier of the province of Alagôas, and indeed in many parts of the province of Pernambuco, this water-worn material is found mingled in bogs with the remains of extinct, gigantic mammals.
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> One of the marked characteristics of this post-tertiary formation is that it is much coarser inland, and grows finer as the coast is approached. The

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[1] Trans. Amer. Phil. Soc., 1889, XVI., 421.

explanation of this water-worn material seems to be that the Tertiary period was closed by a depression along the present coast, which carried the beach line far inland, or that it was already there. Then followed a gradual emergence,[1] during which the whole area now covered by this widely distributed water-worn material was passed gradually through the condition of a beach, upon which the then loose, angular, surface rocks of the country were rounded and worn into the boulders, cobbles and pebbles which we now find scattered over this region. While the surf was beating upon and wearing the hard crystalline and metamorphic rocks of the interior it was unable to produce any very marked effect upon the topography of the country, but when, in the course of the land's emergence, the soft, sandy and clayey beds of the Tertiary were brought up within its reach, the work of land sculpture it was able to do was enormously increased. During the emergence of these Tertiary beds they were deeply eroded, and the mud which originally made part of them was washed seaward, and the coarser materials were concentrated upon the slowly receding beach. In some places these accumulations assume unusual proportions, as if they had been brought together by the gradual beating of waves along a beach, or had been reconcentrated by later streams."

GLACIAL TOPOGRAPHY.

Agassiz considered that the undulating outlines of the topography about Rio de Janeiro were attributable to glacial action,[2] though he recognizes the fact that nothing of glaciation was to be learned from their appearance.[3] A careful study of those features, made with this suggestion in mind, shows that the rounded hillsides have no uniformity in their arrangement, that is, what would be *stoss* sides, judging from the topographic forms, face now in one direction, and now in another, and that the outlines are simply those produced by ordinary decomposition and erosion, though much influenced by structural features. Hartt's opinion, as originally expressed in his book (p. 33), was that the forms of the hills were "due primarily to subaërial denudation."

THE ABSENCE OF STRIÆ.

A bit of negative evidence of great importance against the glacial hypothesis is the fact that nowhere has there been found a single scratch either upon the rocks in place or upon a boulder, cobble, or pebble, that could, by any legitimate stretch of the imagination, be attributed to glacial action. And it is but just to recall the fact that both Agassiz and Hartt recognized this as the one piece of evidence, above all others, lacking for their Brazilian glacial theory. How diligently Agassiz searched for such evidence one can judge from the story of his journey as told by Mrs. Agassiz and himself, and I know that Hartt left no stone unturned and no locality unexplored that he thought might afford him the long-sought striæ. They both explained the absence of such marks by supposing that they had been obliterated by the decomposition of the rocks, and Agassiz believed that in the Amazon region there were no rock surfaces exposed.[1] But it cannot be considered credible that glacial striæ should have been preserved in Asia, Africa and Australia since Carboniferous times,[2] but entirely obliterated in Brazil, both from the bed rocks and from the conglomerates deposited in post-tertiary times, or as has already been mentioned, that the pitted and water-worn faces should have been preserved in these materials while the ice marks should have been obliterated.

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[1] See also Pissis in Comptes Rendus de l' Acad. des Sci., 1842, XIV., 1046.

[2] Geological Sketches, II., 157. Bul. de la Soc. Géol. de France, 1867–8, XXV., 687.

[3] Journey, pp. 69–70.

James E. Mills, a professional geologist and a former pupil of Agassiz at Harvard, spent nearly two years in Brazil in the states of Rio Grande do Sul, Rio de Janeiro, and Minas Geraes. He expresses his views of the subject of glaciation in that country as follows:[3] "In those portions of Brazil which came within my field of observation there is no glacial drift, and there are no glaciated rock surfaces or glacial topography or other signs of the existence of glaciers."

Agassiz points out the weakness of his own theory regarding Brazilian glaciation very nicely in his letter to Professor Pierce, of Harvard, by saying: "But I have not yet seen a trace of glacial action proper, if polished surfaces and scratches and furrows are especially to be considered as such."[1]

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[1] Journey, 426. There are plenty of rock surfaces in the Casaquiari region, on the Araguary, the Tocantins, the Tapajos and in hundreds of other places away from the immediate alluvial plain of the Amazon.

[2] Geological Magazine, 1886, 492–495. For the literature of the subject see C. D. WHITE in Amer. Geologist, May, 1889, 299–330.

[3] American Geologist, III., 361.

BIOLOGICAL EVIDENCE.

Thus far I have confined myself to a statement of the facts that relate directly to glaciation. Aside from these a matter of the utmost importance is the continuity of life from Tertiary times down to the present, especially in the tropical and subtropical parts of the earth. If glaciation had been cosmic, as suggested by Agassiz—if it had taken place under the very equator—then the reasoning of biologists regarding the origin and distribution of the present life of the globe is about all at fault. A reviewer of Hartt's Geology of Brazil long ago called attention to the fact that "the grand objection to the theory of the former existence of a continental glacier in tropical America, is the unbroken continuity of tropical life since the close of the Tertiary period."[2] Mr. Wallace, in an earlier review, had already called attention to the same point,[3] while still another lays stress upon the important fact that the plants found in the Amazonian silts, supposed by Agassiz to be of glacial origin, are the remains of tropical plants, and are not therefore comparable with the Alpine plants growing beside existing glaciers in mountainous regions.[4]

THE OPINIONS OF OBSERVERS.

The following are some of the opinions of geologists regarding the phenomena regarded by Agassiz and Hartt as glacial. These authors are quoted, not simply for the purpose of bringing the weight of authority to bear on the subject, but because they have all seen much of the geology of Brazil and are competent to have opinions worthy of consideration. Darwin, who visited Brazil in 1832 and saw something of these phenomena, stated that no true glacial boulders had been seen in the inter-tropical regions.[1] The English botanist, George Gardner, gives the correct explanation of the formation of the soils about Rio.[2] Burmeister, who traveled extensively in Brazil, is of the opinion that the facts appealed to by Agassiz in support of his glacial hypothesis for Brazil are to be explained otherwise.[3] Liais' adverse opinion has already been cited. Dr. Guilherme S. de Capanema, a Brazilian geologist, thoroughly disbelieves in the theory of Brazilian glaciation.[4] Professor James Orton's papers in which he controverts the glacial hypothesis in so far as it relates to the Amazon valley have been cited, while Hartt himself recognized the mistake of Agassiz in that region.[5] Mr. James E. Mills saw some of the best examples of the supposed glaciation at Rio de Janeiro and spent more than a year in the highlands of Brazil; his opinion regarding what he saw has already been quoted. Professor Derby in speaking of the possibility of glaciaation omits all reference to the phenomena upon which Agassiz and Hartt placed so much stress, namely, those in the mountains about Rio, though to my knowledge, he is perfectly familiar with those phenomena.[6]

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[1] Journey in Brazil, 88.

[2] American Naturalist, 1871, V., 36.

[3] Nature, 1870, II., 511.

[4] The Geological Magazine, 1868, V., 458.

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[1] Trans. Geol. Soc. London, 1842, 2nd Ser. VI., 427.

[2] Jour. Roy. Hort. Soc., 1846, p. 191.

[3] Description Physique de la République Argentine par Dr. H. Burmeister, Paris, 1876, II., 393.

[4] Decomposição dos penedos do Brazil, Rio de Janeiro, 1866; Revista do Instituto Historico do Brazil, 1866, XXIX., 421.

[5] Am. Jour. Sci., 1871, 295.

[6] In the following references more or less doubt is expressed regarding the glaciation of Brazil:

The Highlands of Brazil, by RICHARD F. BURTON, London, 1869, I., 39, II., 218. The Amazon and Madeira Rivers, by FRANZ KELLER, New York, 1874, 47. Fifteen Thousand Miles on the Amazon, by BROWN and LIDSTONE, London, 1878, 42. Brazil, the Amazon and the Coast, by HERBERT H. SMITH, New York, 1879, 634. Glaciers, by SHALER and DAVIS, Boston, 1881, 47. A Geographia Physica do Brazil por J. E. WAPPEUS, Rio de Janeiro, 1884, 55. Pre-historic America, by the MARQUIS DE NADAILLAC, edited by W. H. DALL, London, 1885, 18, foot note. Report on Coffee Culture, by C. F. VAN DELDEN LARENE, London, 1885, 24. Le Pays des Amazones par F. J. de SANTA-ANA NERY, Paris, 1885, 36. A Year in Brazil, by H. C. DENT, I may sum up my own views with the statement that I did not see, during eight years of travel and geological observations that extended from the Amazon valley and the coast through the highlands of Brazil and to the head waters of the Paraguay and the Tapajos, a single phenomenon in the way of boulders, gravels, clays, soils, surfaces or topography, that could be attributed to glaciation. A glacial origin for certain gravels has probably been suggested by Derby,[1] because their origin is somewhat obscure, but I am of the opinion that they admit of the same explanation as the high river gravels of the south-western United States, and that glaciation had nothing whatever to do with them.[2]

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London, 1886, 424. Three Thousand Miles through Brazil, by J. W. Wells, London, 1886, II, 373–4. Sparks from a Geologist's Hammer, by ALEXANDER WINCHELL, Chicago, 1887, 180. Notes of a Naturalist in South America, by JOHN BELL, London, 1887, 313–318 and 342. Darwinism, by ALFRED R. WALLACE, London, 1889, 370.

[1] WAPPEUS' Geographia Physica do Brazil, p. 55.

[2] It may have some value as corroborating an opinion formed before studying the geology of the Southern United States, that all the phenomena brought forward in support of the glaciation of Brazil are repeated in the Southern States, far south of what geologists readily recognize as the utmost limits of glacial ice. In Arkansas for example, boulders occur near Little Rock, of such shape, character, and distribution as to strongly suggest a glacial boulder train, if the glaciation of the region were admissible, or another explanation were not evidently the correct one. For an illustration of such boulders see Annual Rep. Geol. Survey of Arkansas for 1890, II., 25.